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INFLUENCE OF A NEW GENERATION OF OPERATIONS SUPPORT SYSTEMS ON CURRENT SPACECRAFT OPERATIONS PHILOSOPHY :

THE USERS FEEDBACK

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ABSTRACT

Current trends in the spacecraft mission operations area (spacecraft & mission complexity, project duration, required flexibility,...) are requiring a breakthrough for what concerns philosophy, organization and support tools.

A major evolution is related to space operations "informationalization" (ref 1), i.e adding to existing operations support & data processing systems a new generation of tools based on advanced information technologies (object-oriented Programming, artificial intelligence, data bases, hypertext,...) that automate, at least partially, operations tasks that used be performed manually (mission & project planning/scheduling,operations procedures elaboration & execution, data analysis & failure diagnosis,...)

All the major facets of this "informationalization" are addressed at MATRA MARCONI SPACE, operational applications have been fielded and generic products are becoming available.

These various applications have generated a significant feedback from the users (at ESA, CNES, ARIANESPACE, MATRA MARCONI SPACE,...), which is now allowing us to precisely measure how the deployment of this new generation of tools, that we called OPSWARE^{TM}, can "reengineer" (ref 2) current spacecraft mission operations philosophy, how it can make space operations faster, better and cheaper.

This paper can be considered as an update of the keynote address "Knowledge-Based Systems for Spacecraft Control" (ref3) presented during the first "Ground Data Systems for Spacecraft Control" conference in Darmstadt, June 1990, with a special emphasis on these last two years users feedback.

KEYWORDS : Mission control, operations, automation, artificial intelligence, object-oriented programming, planning, scheduling, procedures, diagnosis, documentation, reengineering.

1 - INTRODUCTION

A major lesson of the 1st "Ground Data Systems for Spacecraft control " conference in Darmstadt, June 1990, was the emergence of new operations support tools, based on advanced information technologies (e.g artificial intelligence), in various domains such as mission planning, operators assistance or failure diagnosis (ref 3).

The deployment of these first tools was very promising, but appeared at that time as separated initiatives. Things have changed at lot during the past two years, and a more global and more significant evolution can be noticed today, affecting the nature and also the economics of space operations.

2 - NEW CHALLENGES FOR SPACE OPERATIONS

Current trends in spacecraft mission operations are requiring a breakthrough for what concerns philosophy, organization and support tools, in order to meet a sufficient level of safety, productivity and mission return :

a - the human operator is facing spacecraft which are becoming more and more complex

b - space missions management complexity is increasing

c - space projects duration is continuously increasing, thus creating problems of expertise & experience capture

d - space systems require more and more flexibility and adaptability

e - space missions are generating huge amount of data, from which essential informations are very difficult to extract.

Such a breakthrough is currently being implemented by the "informationalization" (ref1) of space operations, i.e a more efficient management of informations generated and used by space operations, and the automation of operations tasks, which used to be performed manually.This"informationalization"corresponds to the deployment of a complete set of tools, in addition to current operations and data processing systems. We propose to call OPSWARE^{TM} this new level in ground data systems. OPSWARE^{TM} covers all the major mission operations tasks, as presented at figure 1.

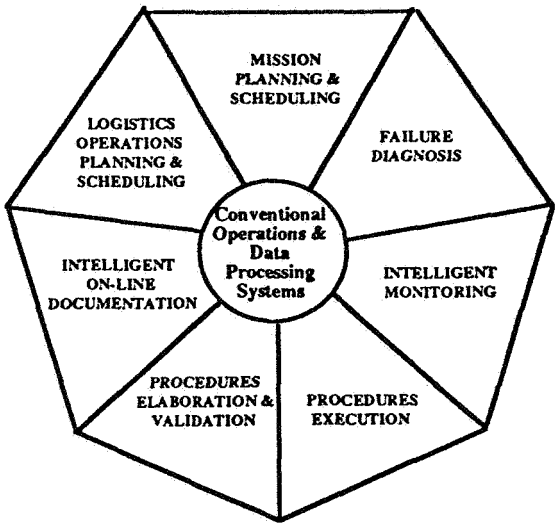

Fig. 1 - OPSWARE^{TM} :
A complete set of tools

The major evolution , since the previous conference in Darmstadt, has been the global and consistent deployment of this set of tools, while two years ago, only isolated applications were paving the way for this larger wave.

And clearly, some applications, which were developped during this period, have demonstrated significant results with reference to safety, productivity or mission return .

3 - SOME BRILLIANT ILLUSTRATIONS

During the past two years, numerous OPSWARE^{TM} applications have been deployed, which address the various facets of OPSWARE^{TM} as presented at figure 1.

Figure 2 gives a non-exhaustive list of some examples, developped by MATRA MARCONI SPACE .

OPSWARE^{TM} FACET	CUSTOMER(S)	APPLICATION
MISSION PLANNING & SCHEDULING	ESA/ESTEC	PLAN ERS FOR ERS-1 EARTH OBSERVATION SATELLITE MISSION STRATEGY DEFINITION AND SIMULATION
LOGISTICS OPERATIONS PLANNING & SCHEDULING	MMS	ARIANE 4 EQUIPMENT BAY ASSEMBLY, INTEGRATION & VALIDATION
INTELLIGENT ON-LINE DOCUMENTATION	MMS	COMMUNICATIONS SATELLITES OPERATIONS MANUAL
PROCEDURES ELABORATION & VALIDATION	CNES, MMS, ESA	POM FOR TELECOM2, HISPASAT & SOHO PROCEDURES ELABORATION
	ESA/ESTEC	PREVISE FOR MANNED FLIGHT PROCEDURES ELABORATION & VALIDATION (SPACELAB, COLUMBUS)
	CNES	PROCSAT FOR SPORT EARTH OBSERVATION SATELLITE PROCEDURES ELABORATION & VALIDATION
PROCEDURES EXECUTION	ESA/ESOC	EXPERT OPERATOR ASSOCIATE FOR MARECS B2 SPACECRAFT OPERATORS ASSISTANCE
	ESA/CNES	CREW SUPPORT SYSTEM FOR ASTRONAUTS ASSISTANCE & TRAINING
INTELLIGENT MONITORING & DATA ANALYSIS	ARIANESPACE	ARIANEXPERT FOR ARIANE 4 POST-FLIGHT DATA ANALYSIS
	MMS	TELECOM2 & HISPASAT SATELLITES PERFORMANCES ANALYSIS
FAILURE DIAGNOSIS	CNES	TELECOM2 FAILURE DIAGNOSIS

Fig.2 OPSWARE^{TM} APPLICATIONS DEVELOPPED BY MATRA MARCONI SPACE

It is very interesting to notice that most of theses applications have produced significant results. Let's have a look at some brillant illustrations.

Plan ERS was used by ESA/ESTEC engineers in 1991 for testing various mission strategies for ERS-1 earth observation satellite (ref 4). The main features of the system were :

- a very flexible planning system thanks to an object-oriented representation of the domain (satellite, resources,...) and a rule-based representation of the mission strategies (e.g. on-board recorder management).

- a powerful planning system, which can handle more than 4000 request in less than 30 minutes

- an environment for mission strategies definition and update, thanks mainly to a syntax-driven editor.

The feedback we got from the users was very positive . Plan ERS allowed the **identification of the appropriate mission strategy for optimizing mission products,** and thus customer's satisfaction.

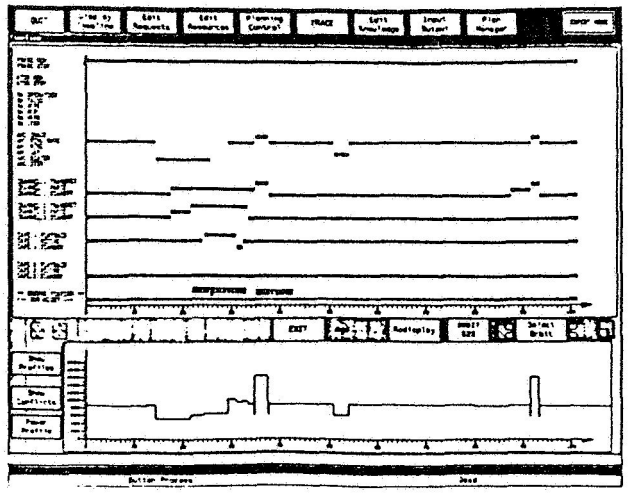

Fig. 3 PLAN ERS TIMELINES & RESOURCES CONSUMPTION PROFILES

POM is a tool developped by MATRA MARCONI SPACE for operations procedures elaboration (ref 5). It has been used in 1991 and 1992 on various satellites projects : TELECOM2, HISPASAT, SOHO.

POM is based on a formal representation of procedures, and on a customized procedure editor. The main benefit of using this tool on the here-above mentioned projects was a **significant reduction of operations preparation phase duration (50%).**

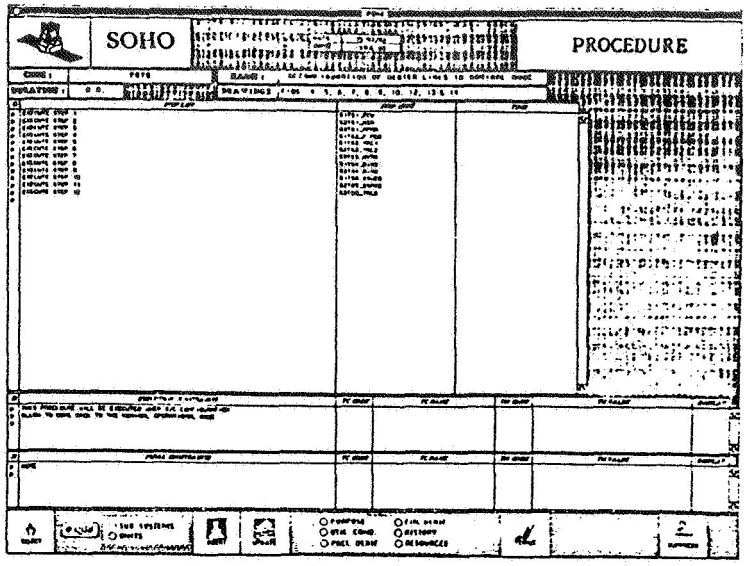

Fig. 4 - POM PROCEDURE EDITOR

ARIANEXPERT has been operationnally used at ARIANESPACE since january 1991 for ARIANE 4 launcher post-flight analysis (ref 6). Its main features are :

- a rich set of signal processing and graphical tools
- a procedure-based analysis definition
- a tree-based procedures conditional chaining
- flexible syntax-driven and graphical editors
- the generation of a technical memory (archiving of all analysis results)
- automatic report formating through a word processor

The measured benefits of ARIANEXPERT use are significant : **the analysis duration is reduced by 75 % while the analysis is more detailed and goes further than previously and the analysis is more exhaustive and more systematic.**

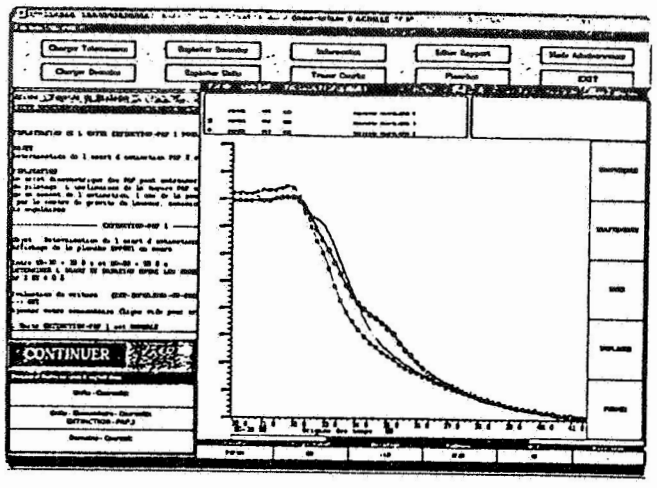

Fig. 5 - ARIANEXPERT DATA VISUALIZATION

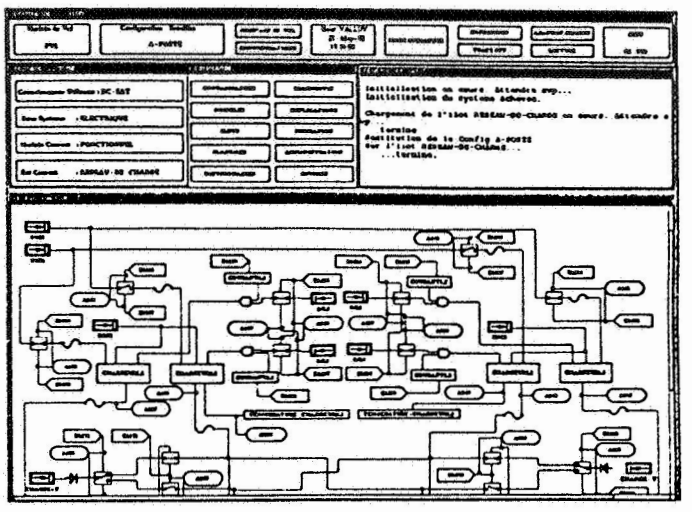

Fig. 6 - TELECOM 2 EXPERT PROPOSED ACCESS TO SPACECRAFT MODELS

TELECOM 2 EXPERT is a knowledge-based failure diagnosis system developped for CNES operators (ref.7). A first complete version of the system has been available since June 1992, and the system will be formally delivered to CNES in January 1993. It is a powerful failure diagnosis system based on various types of knowledge : decision trees encoding the global spacecraft behaviour, and a collection of subsystem functional models capturing the detailed links and interactions that exist between the various spacecraft components. This system is also considered by CNES as an efficient training tool, thanks to its deep knowledge of the spacecraft and thanks to the possibility of session replay. It is also viewed as generating a mission technical memory, allowing the integration of in-orbit experience. Its main benefits are related to **expertise transfer from spacecraft designers to spacecraft operators, and to in-orbit experience capture** (a critical point, if we consider the important turnover in operations staff).

Other brillant OPSWARE^{TM} applications could be mentionned, developped either by MATRA MARCONI SPACE or by other space organizations or companies. These ones clearly demonstrate the deep influence OPSWARE^{TM} tools already have on space operations quality, safety and productivity.

It is also of prime importance to consider that all theses tools are no more developped as completely isolated systems (even if such or such particular project context may lead to this type of conclusion), but are elementary building blocks of a more general concept, the so-called OPSWARE^{TM} level. That is clearly the approach which has been adopted at MATRA MARCONI SPACE (Ref 8), and also by other organization such as ESA/ESOC with the ATOS programme (ref.9).

4 - FROM CUSTOMIZED APPLICATIONS TO GENERIC PRODUCTS

Another interesting evolution is the emergence of generic products for developping OPSWARE^{TM} applications.
Such an evolution definitely shows the maturity OPSWARE^{TM} domain is gaining.

Four generic OPSWARE^{TM} products, developped by MATRA MARCONI SPACE, pretty well illustrate this evolution.

X-ANALYST is a generic product for **intelligent data analysis**, which has been derived from the ARIANEXPERT application (see $ 3). All the technical features which were mentionned for ARIANEXPERT are present within this tool, but they have been made more generic. Since then, X-ANALYST has been applied to other contexts, and more specifically statellites trends analysis. These applications are used by MATRA MARCONI operations department for TELECOM2, and HISPASAT communications satellites, in the context of its customers' support activities, Here again, the main benefits are the reduction of analysis duration and the analysis quality. X-ANALYST application to SPOT2 and SPOT3 satellites is planned.

DIAMS is a generic product for **spacecraft failure diagnosis,** which is derived from the TELECOM2 EXPERT application (see $3). Knowledge representation languages, diagnosis mechanisms, development environment and man-machine interface, which exist in TELECOM2 EXPERT, have been made generic. Developping a new application with DIAMS means essentially acquiring the application-specific knowledge, storing it in DIAMS knowledge base, parametrizing the diagnosis strategy. These tasks are rather natural since they make an intensive use of DIAMS graphical tools, for storing decision trees or subsystems models, for instance. DIAMS is really the right environment for capturing diagnosis expertise of a spacecraft project.

OPTIMUM, derived from the OPTIMUM AIV application sponsored by ESA/ESTEC and developped by MATRA MARCONI SPACE, CRI (Denmark), AIAI (UK) and PROGESPACE (Fr), is a generic product for **managing complex space projects.** Its main features are :

- hierarchical description of the project structure
- optimized computation of AIV plans
- advanced features to ensure the quality of the plan
- planning & scheduling rules
- assistance in monitoring and plan repair
- reporting tools
- interface with DBMS
- interactive graphical interface to edit PERT graph, hierarchical structure of activities, GANTT diagram.

OPTIMUM application to ARIANE 4 equipment bay Assembly, Integration & Validation planning /scheduling has been initialized at MATRA MARCONI SPACE.

OPSMAKER is a generic product for **procedures elaboration and validation .** Based on a formal computerised representation of procedures, its main features are :

- a generic kernel for operations procedures verification, formating and execution, based on a procedure compiler
- a customized procedure editor based on a syntax-driven editor and a database
- an advanced procedure formatter for procedures printing based on a word processor
- an advanced procedure checker, based on process modelling, and providing a rich set of verifications (syntactic, local, temporal, logical,...).

OPSMAKER applications are PROCSAT (sponsored by CNES) for SPOT 4 procedures, and PREVISE (sponsored by ESA/ESTEC) for manned flight procedures (Spacelab, Columbus).

Further to the deployment of numerous applications, the emergence of generic products substantiates the OPSWARE^{TM} domain is maturing. Hereafter, space operations implementation will not be the same !

5 - LESSONS LEARNED FROM THE DEPLOYMENT OF OPSWARE^{TM} APPLICATIONS

As briefly described in §3, MATRA MARCONI SPACE has delivered several OPSWARE^{TM} applications, thus giving an interesting user's feedback.

It is possible to extract some rules from this feedback:

a - OPSWARE^{TM} systems can be implemented as extensions to existing space operations and data processing systems. Some implementations are rather straight forward (intelligent on-line documentation, failure diagnosis, procedures elaboration & validation,...). Some others may require some adaptations of the existing operations & data processing infrastructure for enabling it to integrate OPSWARE^{TM} modules (operations execution, mission planning & scheduling,...). But the great point is that OPSWARE^{TM} systems can be added to existing infrastructure. The evolution in the way operations tasks are performed, associated to OPSWARE^{TM} implementation, is probably more significant (see b).

Nevertheless, some current trends is ground data systems for spacecraft control (e.g. distributed architecture, network of workstations,...) are propitious to OPSWARE^{TM} deployment.

b - Users' motivation is crucial to OPSWARE^{TM} implementation success. This is a key factor of success, and it comes from two facts . First, a basic requirement for OPSWARE^{TM} systems is a perfect human-machine synergy, whatever the concerned task is. Second, if operations infrastructure is not necessarily deeply affected by OPSWARE^{TM} deployment, it is completely different for what concerns operations tasks themselves ; they used be performed manually, and are now performed by an "integrated human-machine intelligence" (ref 10). Users' motivation is thus mandatory !

c - A specific lifecycle is required for this type of systems. A first delivery to the user is required as soon as possible during the project, which will give a user's feedback very early, and so will guarantee the matching between system specified functionalities and the actual needs of the user. More generally, an incremental development is required to rapidly implement changes, which may be frequent for this kind of tools. The programming technologies which are used in OPSWARE^{TM} systems (object-oriented programming, artificial intelligence, hypertext, interface builders,...) perfectly support such a lifecycle (ref 2).

d - A more general lesson, which has been illustrated in this paper, is that **OPSWARE^{TM} is operational now, and has already deeply modified space operations philosophy, and has demonstrated a R.O.I (return on Investment).**

6 - MAJOR STAKES FOR THE COMING DECADE & CONCLUSIONS

OPSWARE^{TM} deployment is already a major fact in space operations, and OPSWARE^{TM} stakes for the coming decade are paramount. They can be sumarized in"Reengineering Space Operations" (ref. 2). What are they ?

a - Optimizing Space Missions Performances, thanks to powerful and flexible planning & scheduling systems, smarter performance analysis tools and operations support tools allowing a faster operator's reaction.

b - Reducing Space Operations Cost & Duration, thanks to operations automation, and an optimized resources management. This objective is more or less difficult to meet, depending on the nature of the space project ; the problem is completely different between a communications satellites project and a space station program, even if the objectif is critical for both.

c - Enhancing Space Operations Safety, thanks to a better human-machine synergy, and to operations automation providing exhaustivity and systematization. The goal here is to reduce the number of operations errors, which still occur too much frequently in space projects, and which may have critical consequences.

d - Capturing Design Knowledge and In-Orbit Experience, thanks to the implementation of a computer-integrated technical memory and to expert tools for operations support.

These stakes are critical for the success of future space missions, and concern all the international space communities.
OPSWARE^{TM} systems is a key to them. They can play a major role in **making space operations faster, better and cheaper !**

REFERENCES

1 - STAN DAVIS & BILL DAVIDSON 1991

2020 VISION, Transforming your business today to succeed in tomorrow's economy.

A fireside book. Published by Simon & Schister

2 - INFORMATION WEEK, Bonus issue,

May 5 1992
How you fit in... Reengineering... and how you don't

3 - J.M. DARROY, June 1990

Knowledge-Based Systems for Spacecraft Control, Keynote Adress
1st International Symposium on Ground Data Systems for Spacecraft Control
Darmstadt, Germany

4 - J.FUCHS - A.GASQUET - J. MULLER & P. VIAU, May 1991.

The Expert Planning System Prototype : Experimentation & Users Feedback.
3rd ESA/ESTEC Workshop on Artificial Intelligence and Knowledge-Based Systems for Space
Noordwijk, Netherlands

5 - JY MARSON , June 1990

An Hypermedia tool for operational procedures creation and utilisation
1st International Symposium on Ground Data Systems for Spacecraft Control
Darmstadt, Germany

6 - JM BRENOT - Y. PARROD - D. AUBIN & Ch PARQUET, February 1992

ARIANEXPERT : Post-Flight exploitation of ARIANE launcher telemetries recorded during the flight.
FAIST'92 (Fielded Applications of Intelligent Software Technologies)
Toulouse, France

7 - JM BRENOT - Ph CALOUD & L. VALLUY, May 1991

On the development of an operational expert system for the Telecom2 satellite control centre.
3rd ESA/ESTEC Workshop on Artificial Intelligence and Knowledge-Based Systems for Space
Noordwijk, Netherlands

8 - JM DARROY, March 1992

Intelligent Assistant Systems for Spacecraft Operations : the current state of the art
INFAUTOM'92
Toulouse, France

9 - H. LAUE, October 1990

Artificial Intelligence in Space Mission Ground Systems
41st congress of the International Astronautical Federation
Dresden, Germany

10 - JM DARROY , September 1990

Integrated Human-Machine Intelligence in Aerospace.
Conference introduction by the conference chairman.
3rd International Conference on "Human-Machine Interaction & Artificial Intelligence in Aeronautics & Space"
Toulouse, France